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Title: ABLE direct drive multi-shell NIF campaign

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Intended for: Inter-Laboratory shot review for NIF

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ABLE direct drive multi-shell NIF campaign

**M. J. Schmitt, B. S. Scheiner, B. Keenan, D. Schmidt, Lynn Goodwin, L. Kot,
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M. Rosenberg, R. S. Craxton, P. W. McKenty, LLE,
H. Huang, A. Haid, GA**

NIF Council Presentation for FY22 NIF Experiments

March 25th, 2021



Optimization of double shell kinetic efficiencies & symmetry

Description:

- Continuation of 1.1 MJ ABLE double shell shots with improvements to 2PP 3D-printed fine-structured low-density lattice fabrication to demonstrate >50% collision efficiency and simultaneously improve inner shell symmetry with scaled beams and optimized laser drive

Objectives:

- Use self-emission and backlighting to determine shell velocities (and infer kinetic efficiencies) and optimize symmetry of the inner shell

Campaign/Sub campaign: ABLE

Shot RI: Kot

Designers: Schmitt/Scheiner/Keenan

Collaborators: Target fab: Schmidt & Huang(GA)

Risks/Issues:

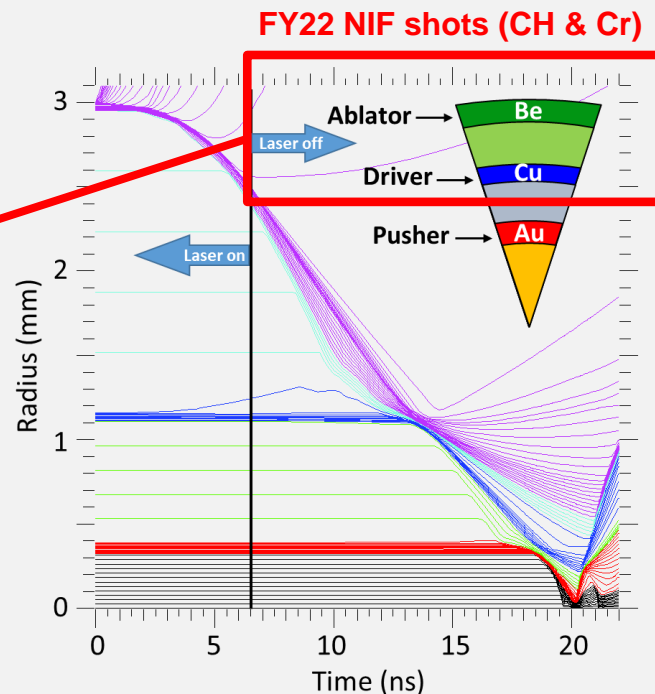
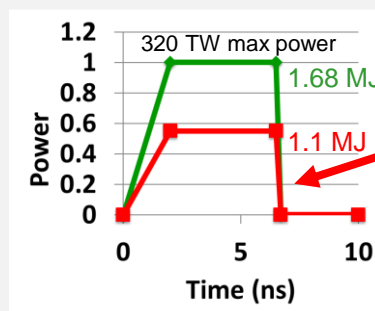
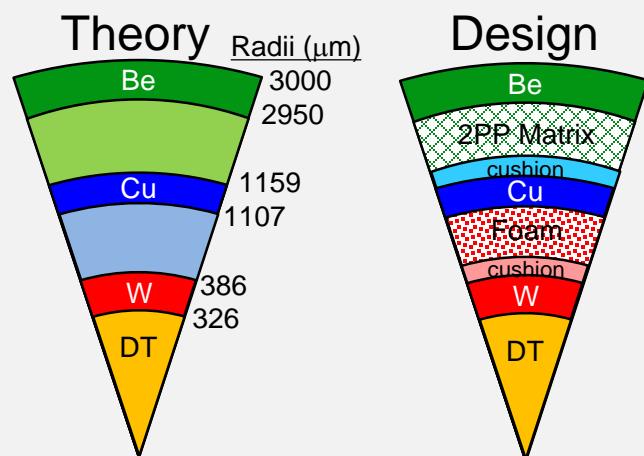
- Finer lattice structures (≤ 3 um struts) at low average density (~ 5 mg/cc) now appear feasible (to maintain shell integrity)
- Control of inner shell symmetry and scaled beam sizes may require graded density lattice near the inner shell

Shot Request Summary for FY22 Q1, Q2, Q3, Q4 (estimate by quarter, extend table as needed)

Shot Type	Q1FY22	Q2FY22	Q3FY22	Q4FY22	Notes:
Low density lattice shot		1 shot			
Thin ablator (1) and graded lattice w/ small beams (2)			1 shot	1 shot	

The ABLE campaign is validating design and fabrication capabilities for multi-shell high-yield NIF targets

Motivation: PDD double shell of outer two shells validates both hydro-efficiency and shell collision efficiency for innovative NIF ignition concept



Goal: Obtain design hydro-efficiency and collision efficiency with predictive shell symmetry

- Results will be used to determine if further development of this ICF concept is warranted
- Fabrication development for double shells and low density lattices dovetail with Double Shell Project.

Experimental Design based on demonstrated ABLE target

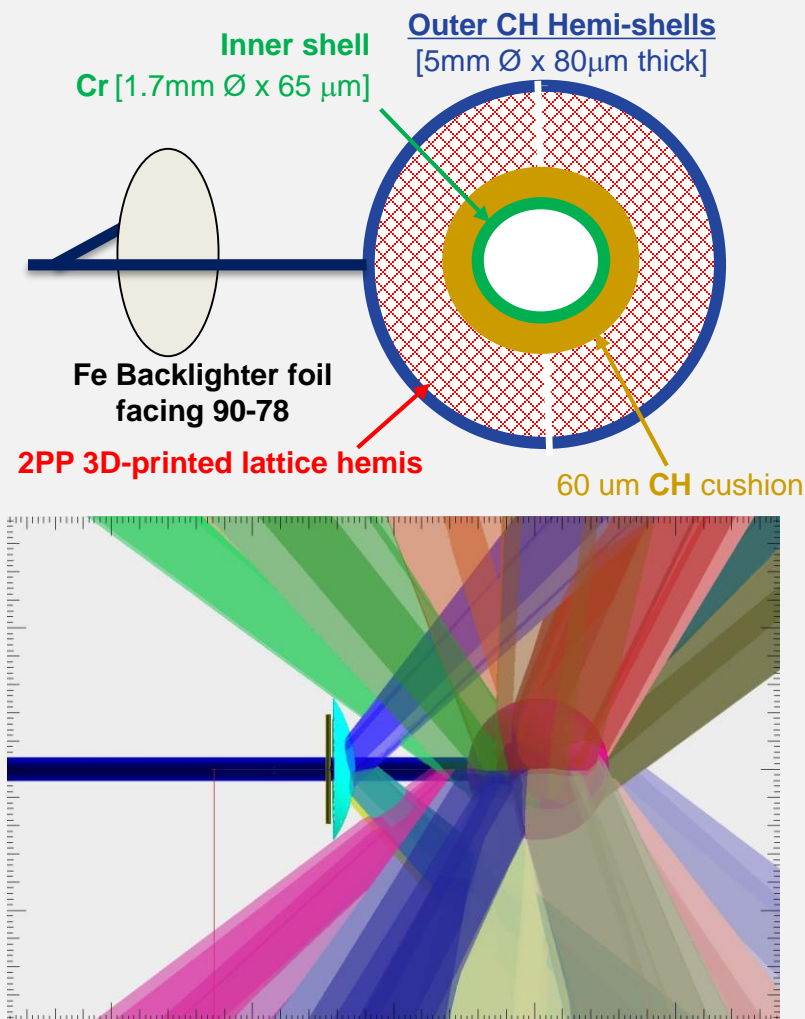
Brief description:

Current ABLE platform will be used for these experiments and include **laser drive adjustments** (pointing, intensity and spot size) combined with **newly created inter-shell lattice materials** with finer structures and tailored density profiles

Each shot moves us closer to a validated design

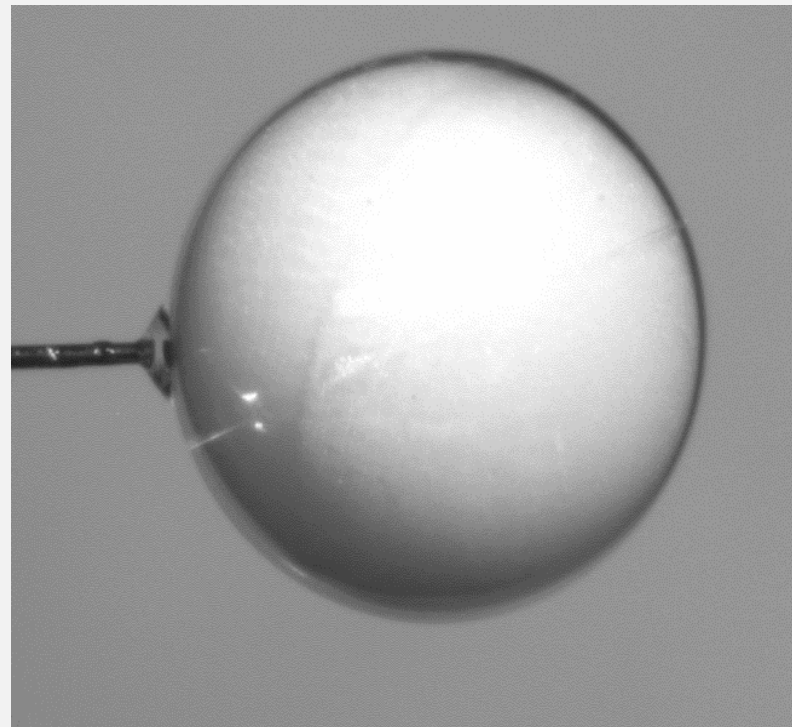
- 1: Lower average lattice density to 5 mg/cm³
- 2: Thinner ablator for 9% hydro-efficiency
- 3: Optimum collision efficiency (~60%) with good inner shell symmetry using optimized lattice/cushion for enhanced stability with minimum laser spot size

ABLE double shell platform:



Because of LDRD investment, fine-detail low-density 2PP matrix hemi's for double shells are now being produced by LANL and GA

- Average lattice densities in the 5 mg/cc range composed of struts with diameters of 3 μm or less are now possible for multi-shell targets
- Fine strut features “isotropize” quickly from drive pre-heat
- Target size determines the time available for achieving uniformity
- Understand the stability of the imploding outer shell versus the morphology of the 2PP lattice is crucial for determining target requirements for multi-shell experiments



Lattice properties

Density ~ 5 - 15 mg/cc

Strut diameter ~ 3 μm

Lattice pitch ~ 50 μm

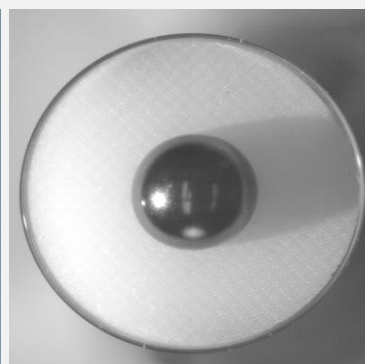
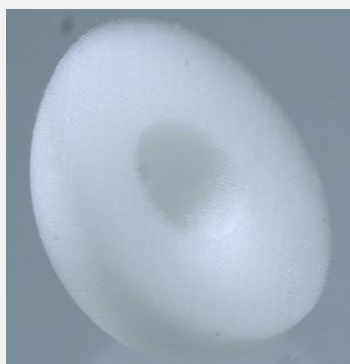
~ 5 mm OD

~ 1.8 mm ID

C: 43.87, H: 43.87,

N: 0.01, O: 12.25 at%

Cubic lattice cell

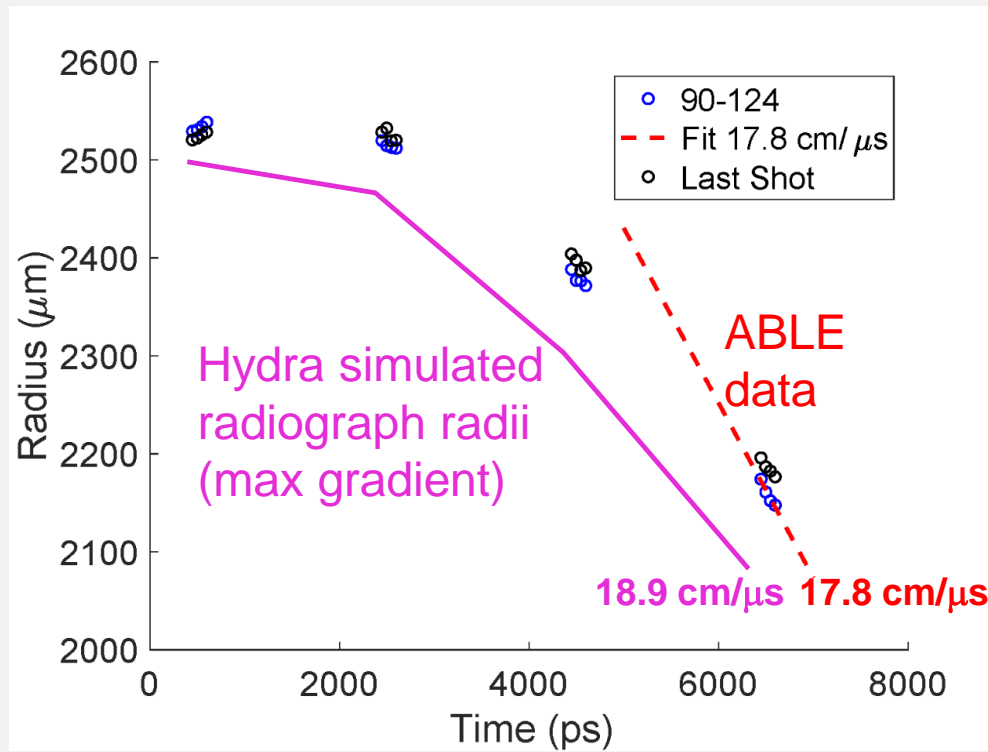


Images courtesy of Derek Schmidt, LANL, and Alex Haid & Haibo Huang, GA

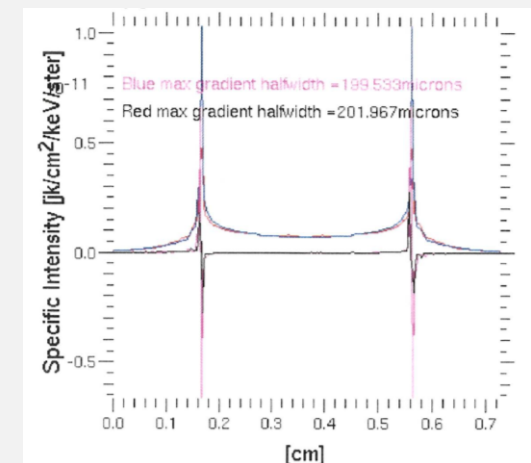
Outer shell hydro-efficiency of 8.2% is determined by comparing SE data from 0-0 and 90-124 framing cameras with simulated radiographs from 2D Hydra simulations

- Hydra is currently over predicting the CH ablator shell velocity by 6%

N201007 (5 mg/cc lattice) and N201217 (vacuum) data
versus Hydra simulated radiograph trajectory



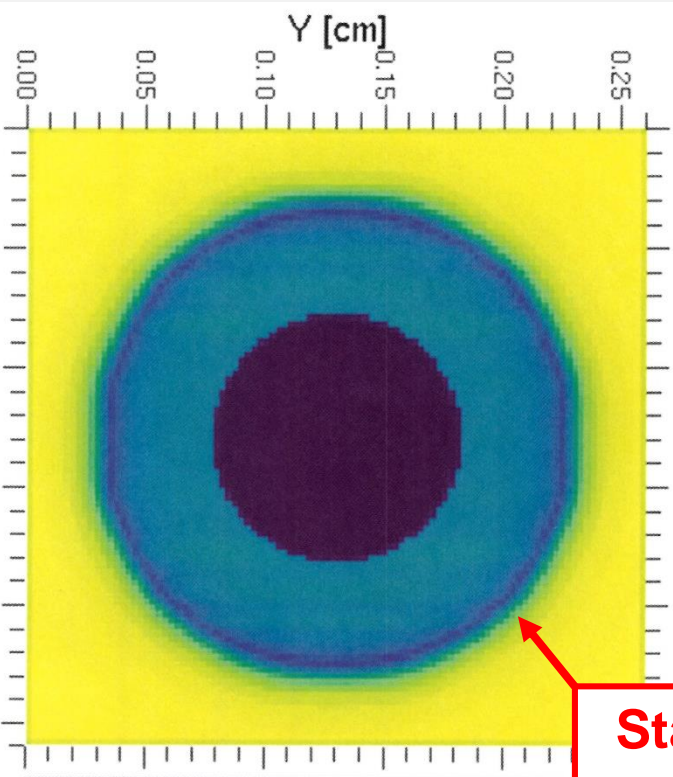
Bk24: 100% drive, $\rho_{\text{lattice}} = 0.1\text{-}5.0 \text{ mg}/\text{cm}^3$,
1.1 drive on 23° beams
 \Rightarrow 98.3% laser absorbed, 25% shell ablated,
 $\langle v \rangle_{\text{CH}} = 18.9 \text{ cm}/\mu\text{s}$ at 6.5 ns, $\eta_{\text{hydro}} = 8.2\%$



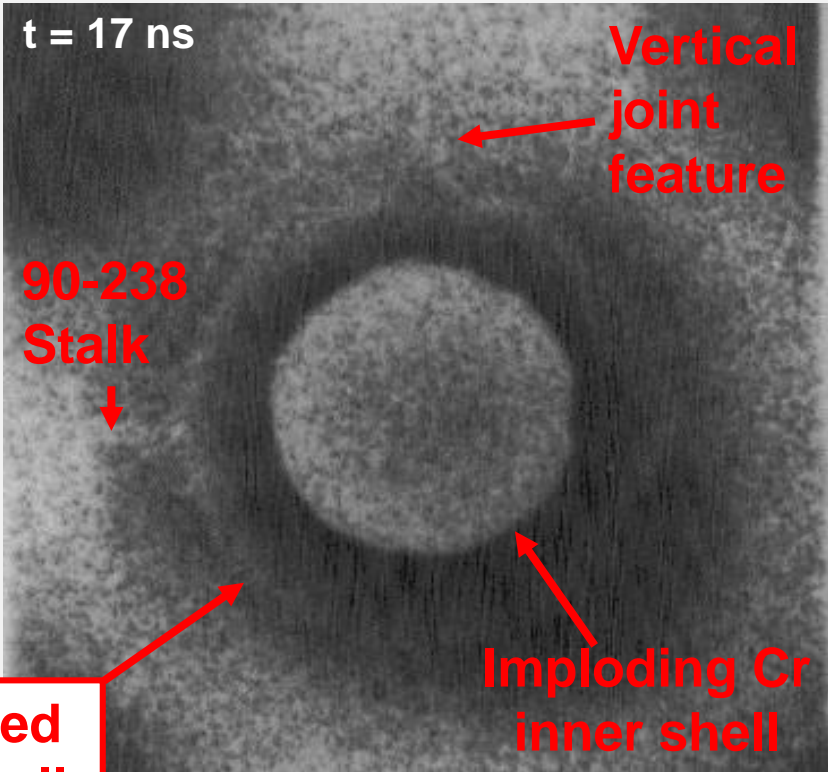
90-78 backlit images show stagnated outer CH shell around imploding inner Cr shell as predicted with 40 mg/cc inter-shell CH foam

Synthetic radiograph from 2D HYDRA

PDD_ABLE_DDD_S05: N200525-001



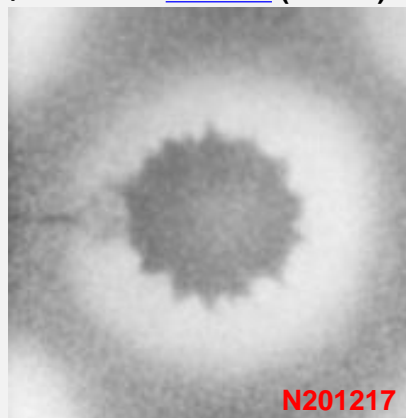
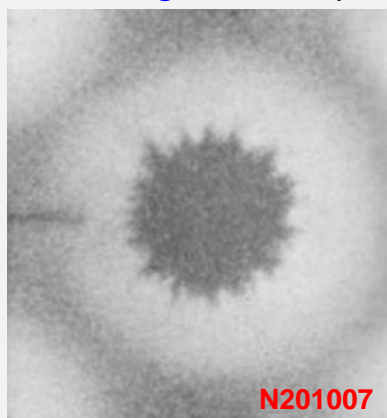
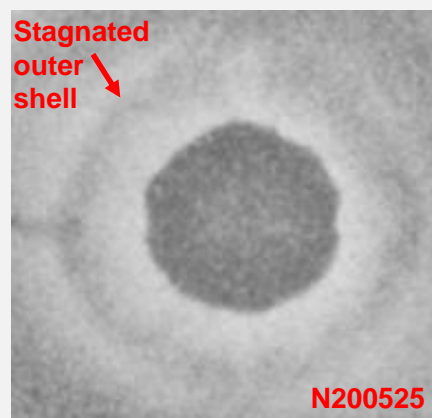
Stagnated
outer shell



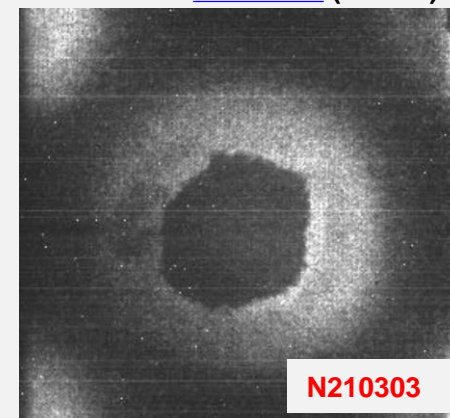
Previous ABLE shots used vacuum, foam, Veronoi lattice and cubic lattice between the two shells

show lattice and beam spot asymmetries

May with [40 mg/cc foam](#) (~18 ns) Oct with [5mg/cc Veronoi](#) (~17 ns) Dec with [vacuum](#) (~16 ns)



March with [GA lattice](#) (~15 ns)



Large laser beam spot sizes
& 90GHz SSD

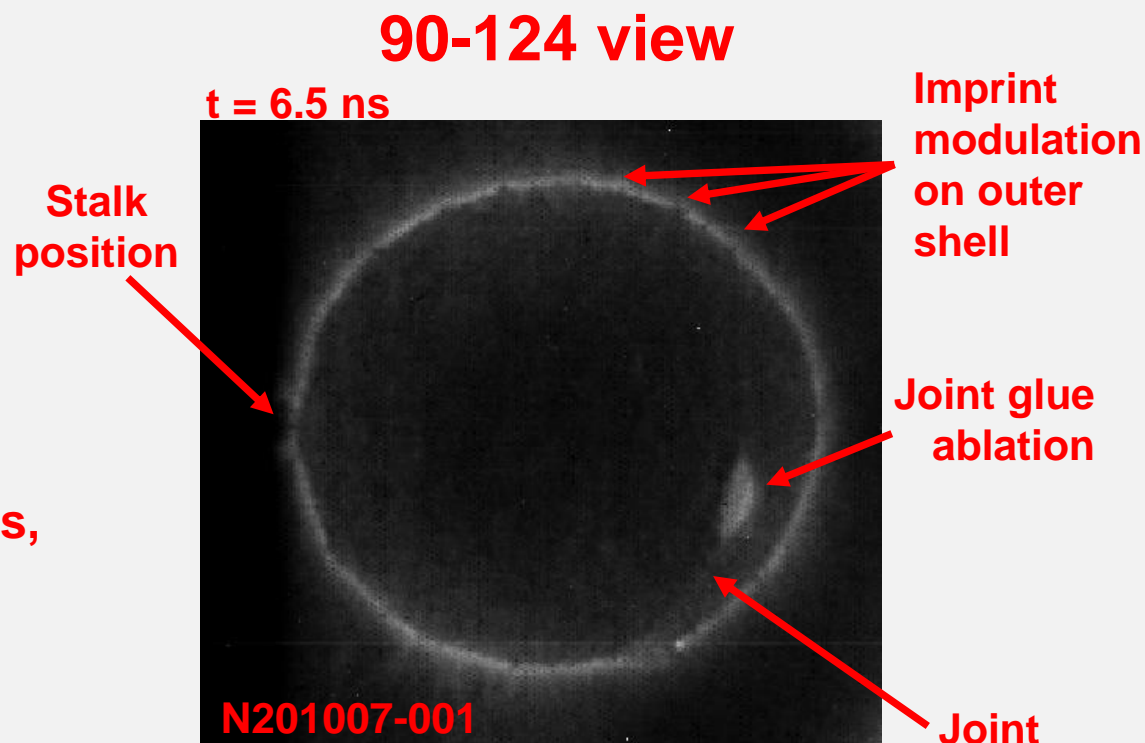
Smaller 5/6 spot size beams
& 45GHz SSD

The equivalent $\rho=1$ thickness of the 41 mg/cc foam volume at the outer radius of the inner shell ($r=.83$ mm) is $260\text{ }\mu\text{m}$ compared to $60\text{ }\mu\text{m}$ GDP cushion on $65\text{ }\mu\text{m}$ Cr shell

Imprint depends on laser drive details and target design “filtering” determined by specifics of the inner shell cushion layer and lattice parameters

Self-emission images of outer shell show imprinting by large-strut low-density inter-shell 2PP lattice

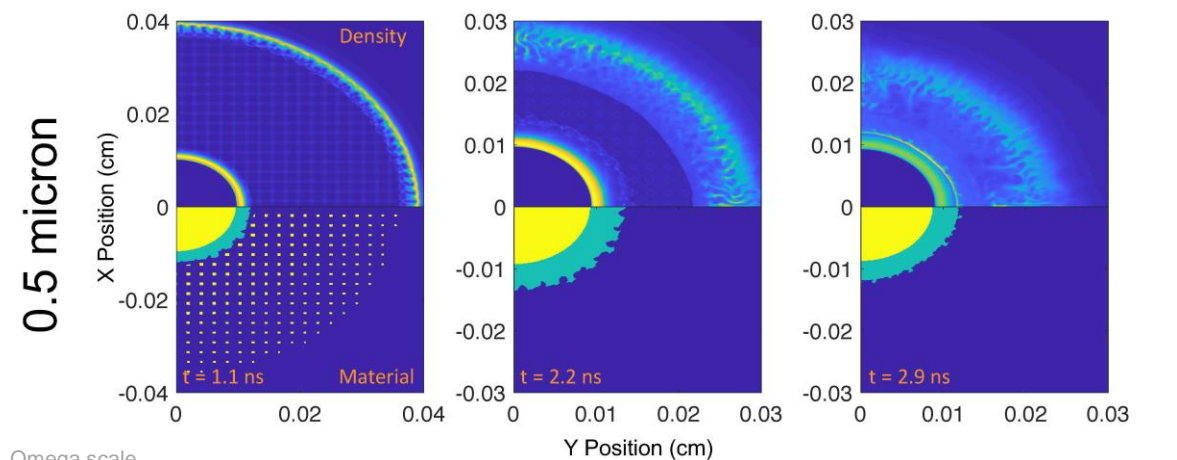
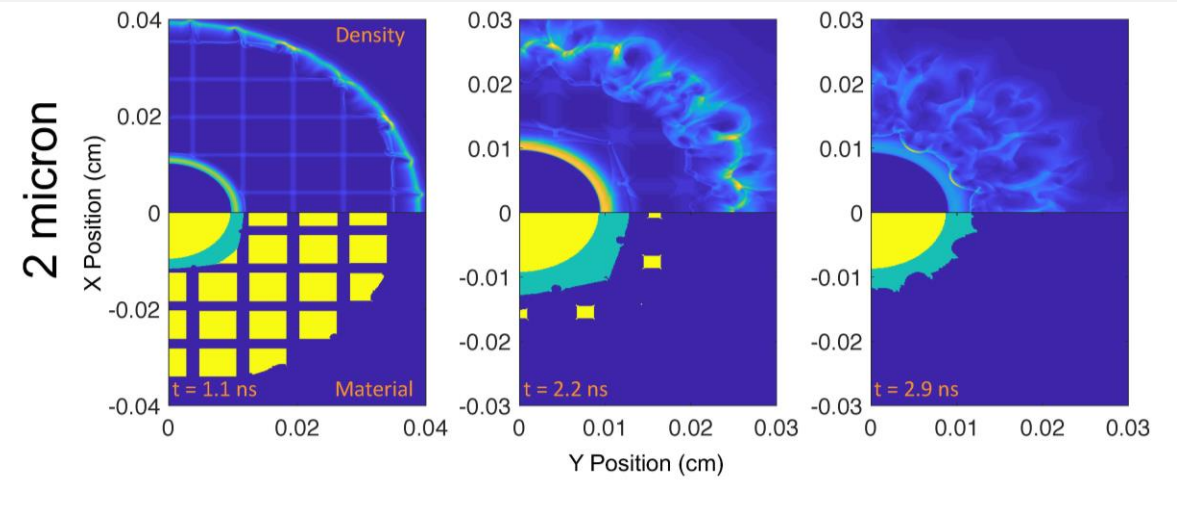
- 5 mm \varnothing x 80 μ m thick CH ablator capsule
- Joint mounted vertically to separate PDD effects from hemi-joint effects
- 2PP lattice had ~ 20 μ m struts, about 7x the desired size of ~ 3 μ m need to blowdown before outer shell implosion



Self-emission images gathered from 0-0 and 90-124 views

Recent 2D xRage simulations* in cylindrical geometry of inter-shell “lattice” show that the lattice structure needs to be fine enough to obtain results consistent with a homogeneous material

- Foams have structures in the 0.1 μm regime (and have negligible imprint)
- 2D simulations (of ribbons) show reduced imprint as ribbon thickness decreases
- 3D strut rods (instead of “ribbons”) will reduce the impact seen here
- Lattices having struts a few μm in diameter should have negligible impact, similar to foams

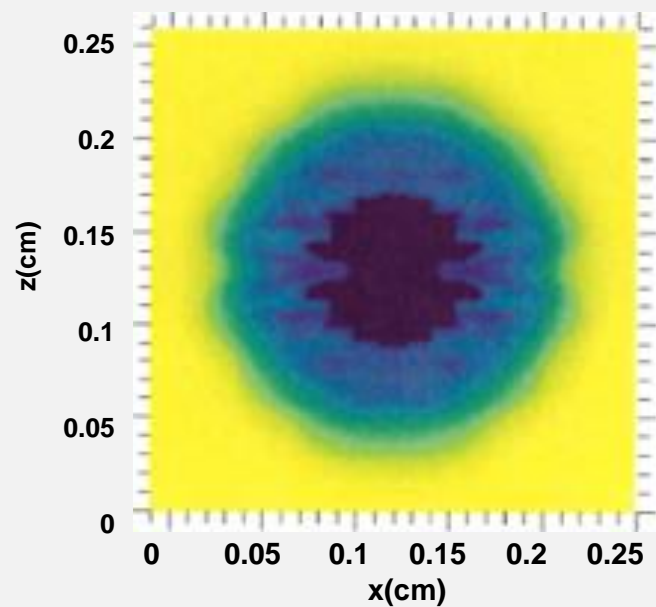


Omega scale
 $3.5 \times 10^{14} \text{ W/cm}^2$,
 40 mg/cc ave
 50 μm outer shell

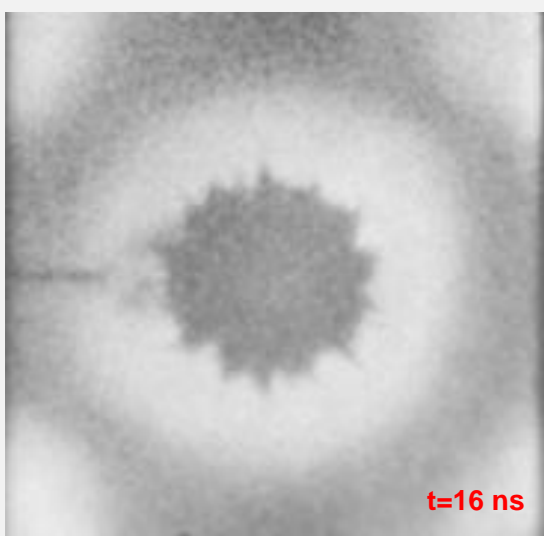
* Simulation results courtesy of Brett Scheiner, XCP-6

Attributing and minimizing the mode spectrum seen on our direct-drive experiments is needed for predictive capability of future designs

Hydra 2D simulation



N201217 NIF data

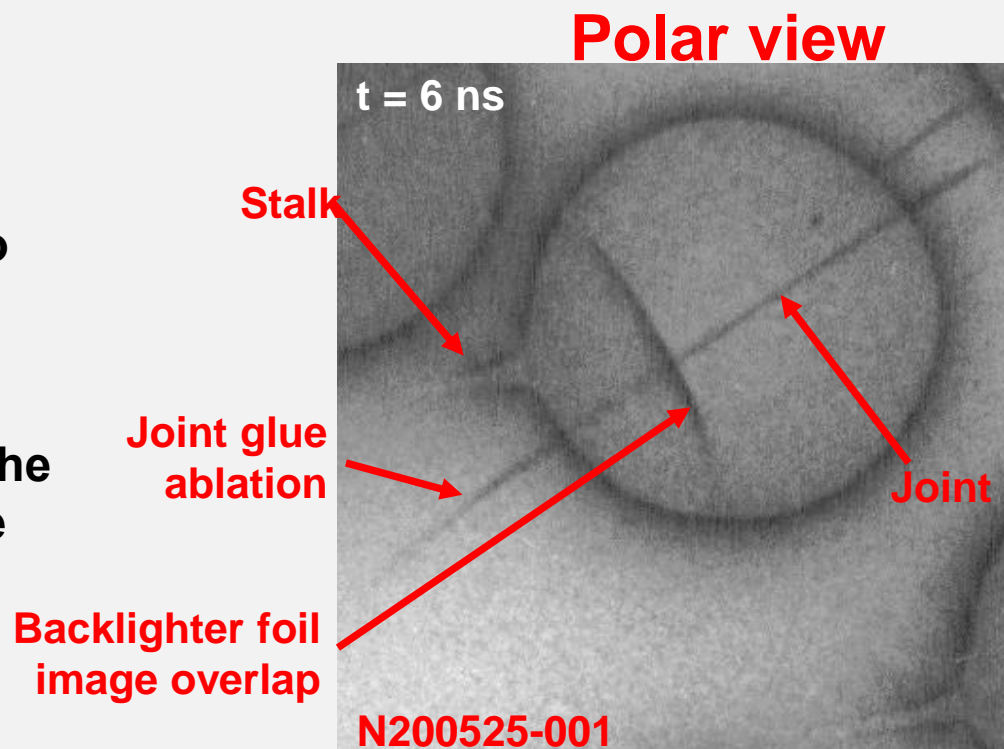


2.8 mm
(14 mm strip with 2x magnification)

Are 3-D simulations needed in indirect drive to predict the drive symmetry features?

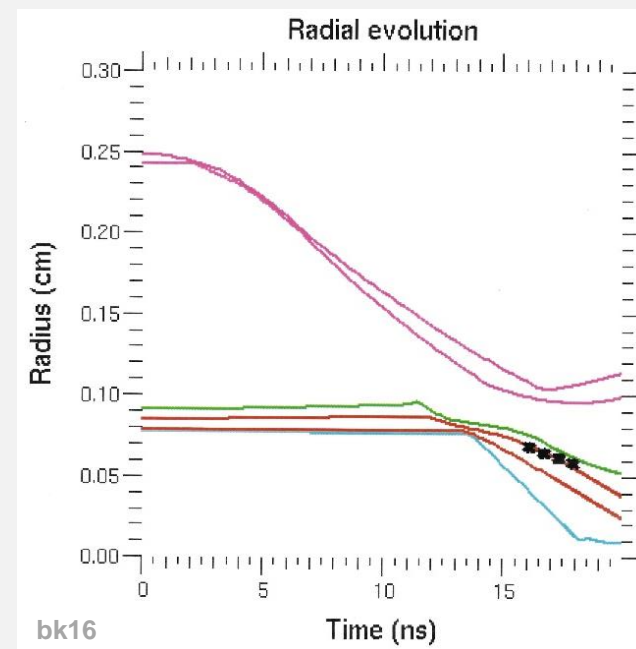
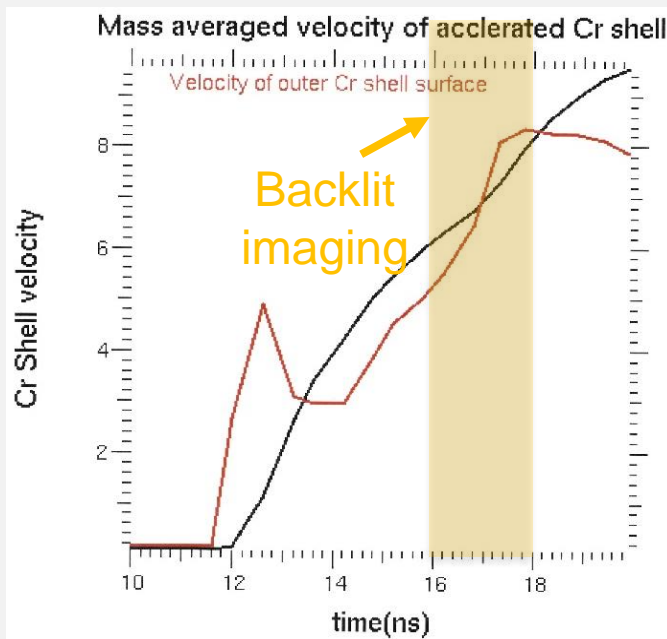
Polar self-emission images show (for the first time!) well confined joint feature with polar direct-drive

- 5 mm \varnothing x 80 μ m thick CH ablator capsule
- Joint mounted vertically to separate PDD effects from hemi-joint effects
- No angular “blow out” of the joint seen at the end of the laser pulse



Self-emission images gathered from both 0-0 and 90-124 views

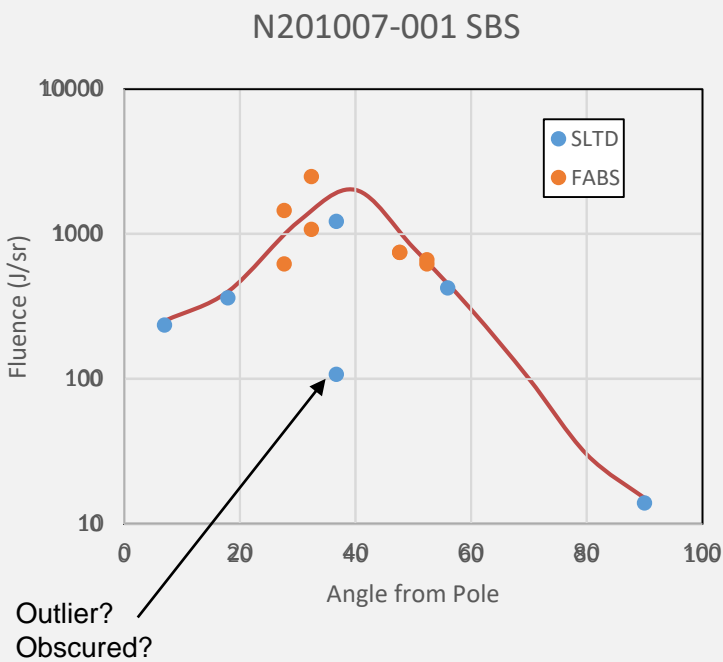
Backlit images of inner shell for of 5/6 scale design with 40 mg/cc inter-shell foam matches simulation using 90% laser drive/absorption



- Outer surface velocity of inner shell should approximate average shell velocity during backlighting

Backlit data in good agreement with post-dicted outer surface position of inner shell, when 7% velocity of outer shell is included

A fit to the SLTD and FABS SBS scattered light fluence data indicates less than 1% total laser scatter for a beam-to-capsule ratio of 0.33



- Piece-wise integral gives 0.63% scattered light of the 1.1 MJ directed to the capsule

Polar angle	Fluence	Energy
7	250	3.718524
18	400	23.70714
30	1200	125.5422
40	2000	224.1668
50	800	106.8661
60	300	45.3081
70	100	16.38872
80	30	5.153183
90	15	2.616666
Integral over theta		553.4675
Energy scattered into 4 π		6951.552
Percent scattered		0.631959

Majority of the scattered light energy is in a narrow angular region near 40°

FABS and SLTD data from shot N201007 courtesy of Mike Rosenberg, LLE

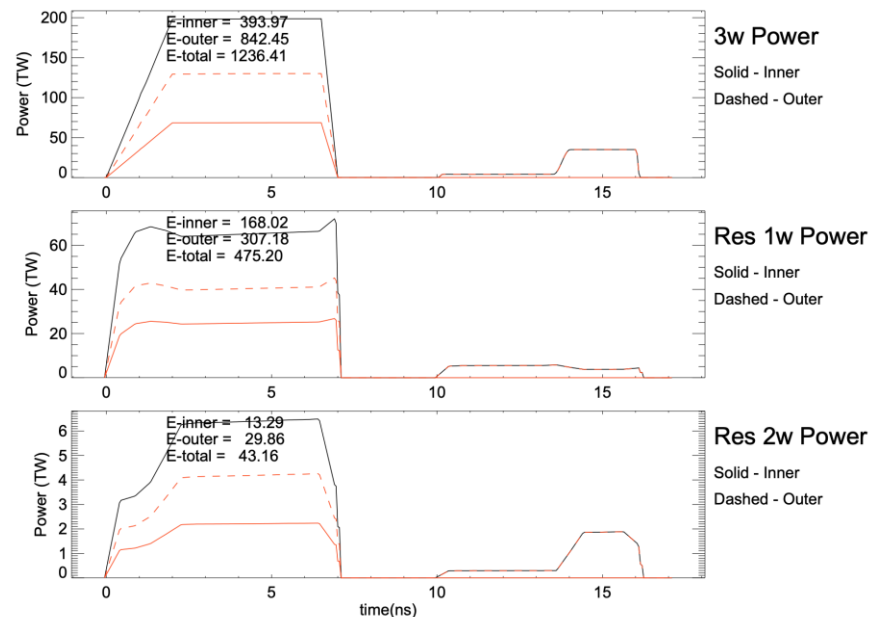
Laser Requirements similar to previous shots

Experiment Layout/Configuration #1 of 1

Laser Parameter	Drive beams	Backlighter
1) Total shot energy	1150 kJ for drive 100 kJ for backlighter	
- Number of beams	176	16 (Q11T, Q11B & Q12B Q12T)
2) Pulse length	6.5 ns (2 ramp and 4.5 main)	0.5 ns prepulse and 2.5 ns main
3) Pulse shape	See plot	See plot
4) SSD bandwidth	90Ghz	Standard
5) CPP use	Standard	Standard
6) Pulse delays	none	10 ns
7) Inner/Outer cone wavelength offset	Any	Any
8) Beam pointing	See split-quad PDD pointing Defocus: +22mm to +35 mm	Backlighter foil Defocus: +2mm to +17 mm
9) Optics Log Growth (192 beam equivalent)	0.11	
10) Is ARC required	NO	

Laser Pulse Shape

I_PDD_PDD_ABLE_P08c Cone Pulse Shapes

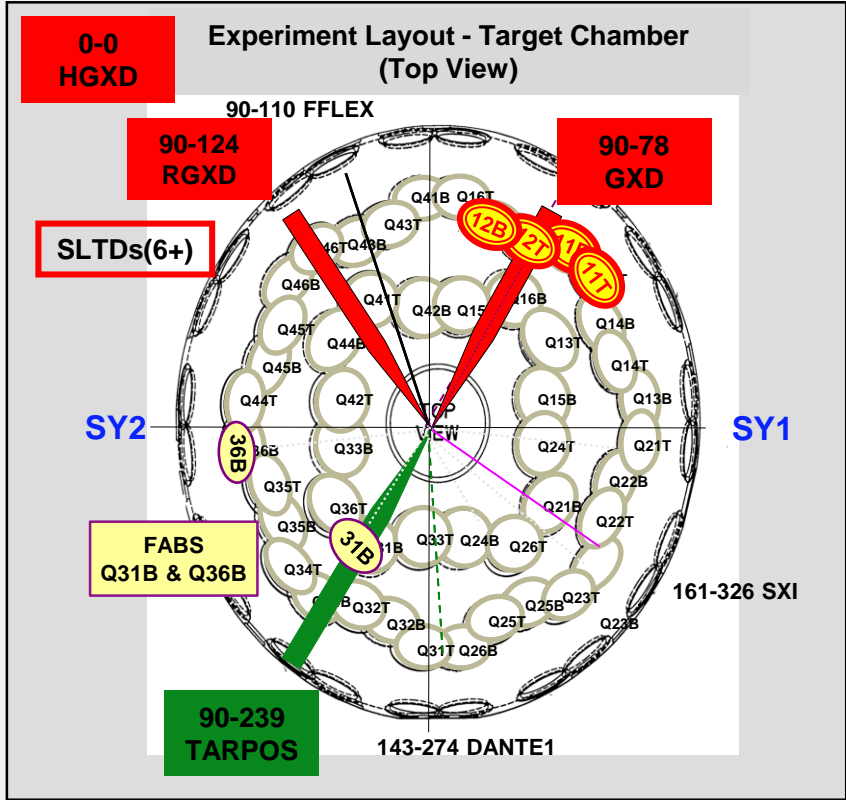


Diagnostic/Facility Configuration same as before

Requested Diagnostics (DIM Info. Required)

Location	Diagnostic/ snout	Priorit y	Type
DIM (0,0)	HGXD5T/1X	1	3
DIM (90,78)	WGXD4F/2X	1	3
DIM (90,124)	TWGXD3F/1X	2	3
Fixed	SLTD (6+)	2	3
Fixed	FABS	2	3
Fixed	SXI-L (G-LEH-2), FFLEX, NBI	3	3

Experimental set-up: One for each unique illumination AND diag config, e.g. if you change either, requires a different setup
Priority: (1: must have, 2: like to have, 3: ride-along) Type: (1: New diag, 2: major mod, 3: minor mod or existing)



New detector requested: No
New snout/configuration requested: 90-78, change in PH size from 20um to 15um
Classified data/diagnostic: No

Answers to PRP Questions from last Council Meeting

- Why are 3 cushion thickness shots needed, can sims reduce shot number needed? Assessment of the imprint of the lattice is needed.

We must fix lattice “fineness” issues first. Initial imprint simulations (shown) have been done. Additional simulations for best matrix/cushion combination will be performed to optimize late FY22 and FY23 shots.

- Can these expts be scaled down to lower log damage?

No. Disassembly of the matrix requires full-scale timing (as shown). We are at a strut diameter resolution fabrication limit. Fully defocused NIF laser beam spotsize effects are also impacting the observed symmetry, so scaled down shots (already done at 0.25 scale on Omega) are problematic.

- Can the diagnostics resolve the imprint? What is the mode spectrum required to be “good enough” for moving forward?

Imprint (shown) is easily seen owing to high Cr shell contrast. Predictive capability of shape and collision efficiency will determine perturbation spatial wavenumber spectrum requirements.

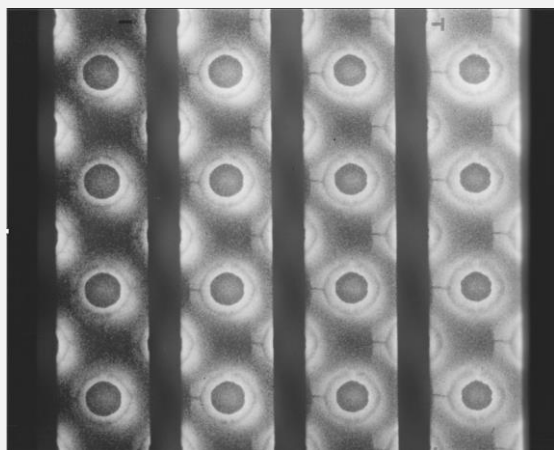
- Are ablator shell physics properly modeled? Previous Be ablator shot implosion differences raise question on opacity and EOS, conductivity, flux limiter accuracy. Are WDM effects an issue? Is laser absorption really 100%?

N200525 BL data of the inner Cr shell (shown) demonstrate the physics modeling of the entire double shell is consistent with scattered light measurements. N201007 and N201217 scattered light data show absorption is $\geq 99\%$ with corrected “best pointing” of laser beams.

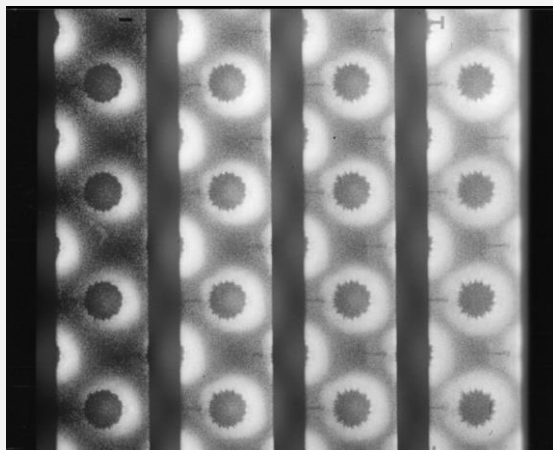
Backup slides and information

Results of 2020 ABLE shots with 45 GHz SSD

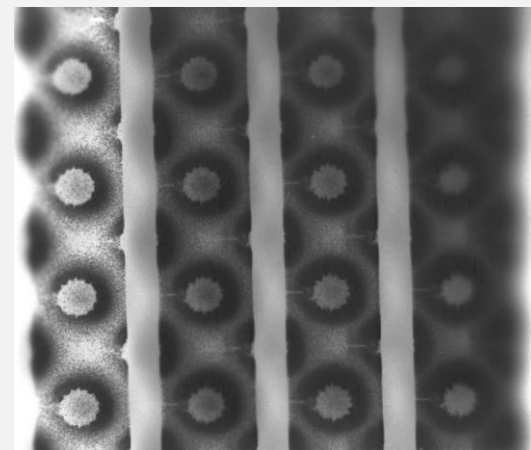
May with 40 mg foam (16 ns)



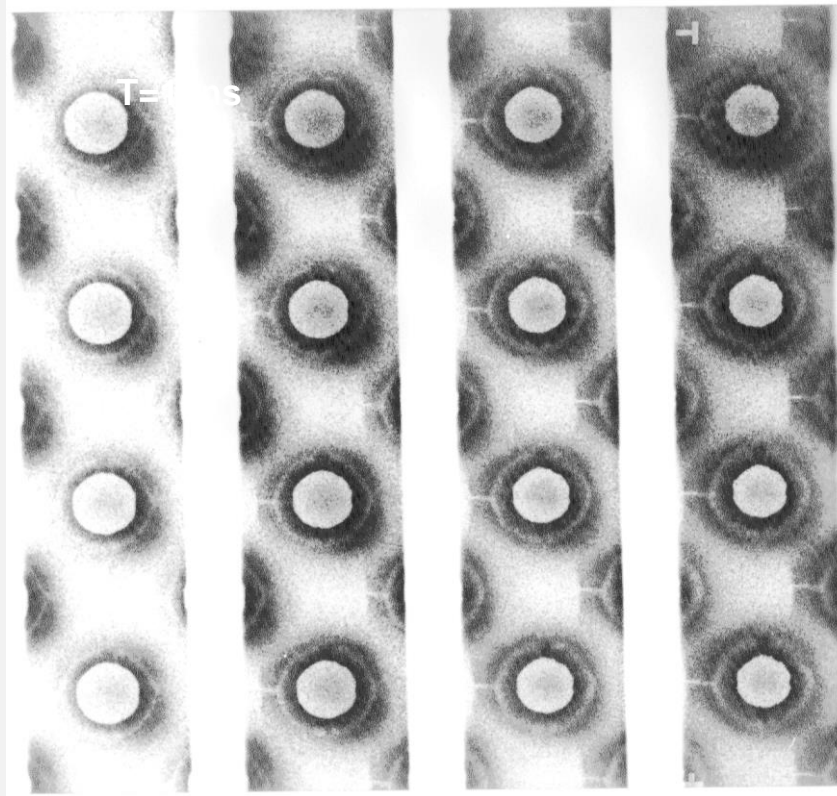
October with 5mg/cc matrix (15.0 ns)



December with vacuum (14.3 ns)



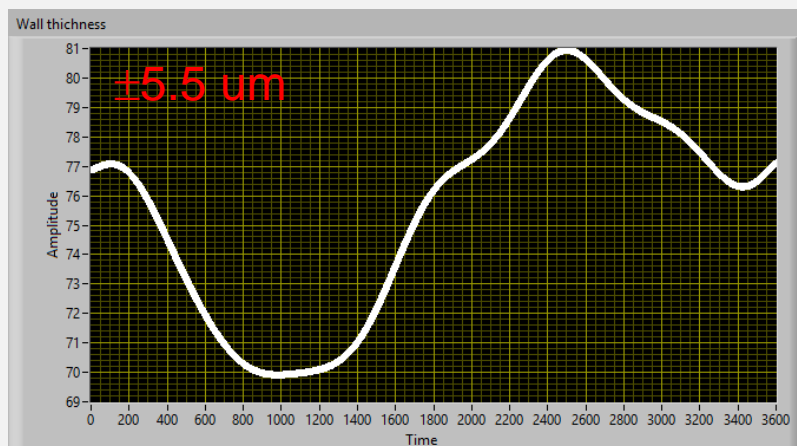
Last image shows modulation from split-quad drive and an equatorial feature



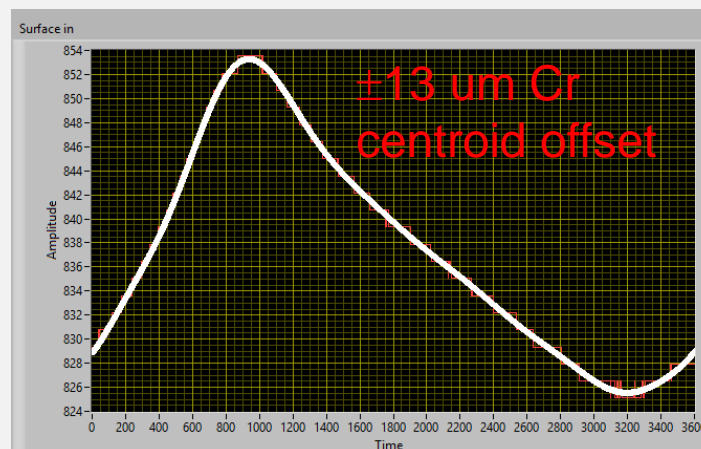
- Last image at ~18ns
- Equatorial feature is not imprint from outer shell joint, because it is vertical.
- What was foam hemi orientation?

Analysis of May double shell images estimates target imperfections

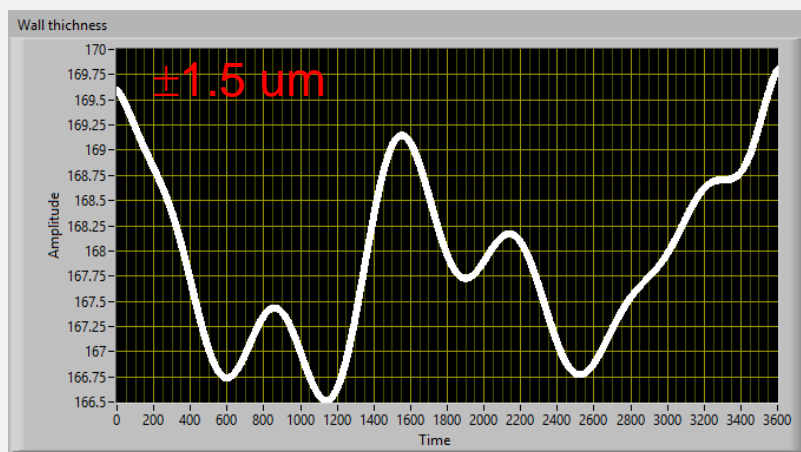
Outer CH shell wall thickness variation



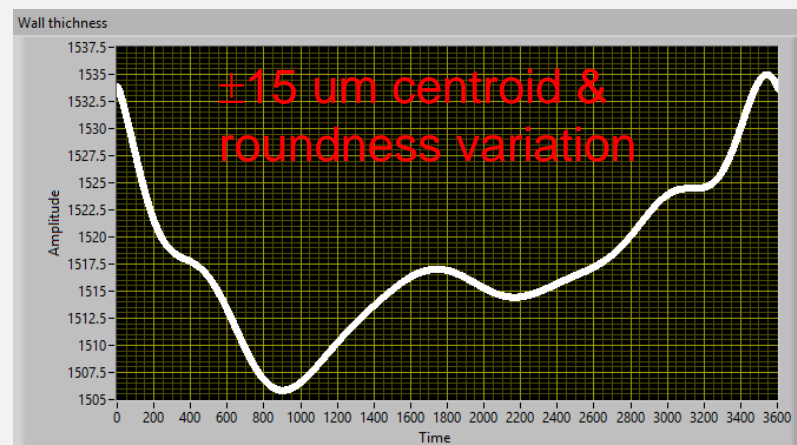
Inner Cr shell outer wall variation



Inner CH cushion thickness variation



Radial distance variation between shells



Data analysis of LANL target image by Haibo Huang, GA

PRP Questions Answered from last HED Council

- State the PRP's questions/comments from the last HED Council session one at a time with an explanation/answer following each. Include any supporting findings and data that are relevant.
- Three different cushions are shown, but only two shots are requested. Which ones will be used?
- **Multi-Shell Direct Drive Ablator Energetics (ABLE):**
- These are expensive (log growth) shots, so it is worth asking if objectives can be achieved at lower E. To assess the impact of cushion variations on coupling and symmetry I don't think full energy is necessary; models could be validated / calibrated at lower E.
- It is not clear however if a reduced E shot can be performed with a full E target, so this may put a burden on target fab. Presumably the campaign also wishes to connect with the FY20 shot at full E as part of the cushion scan.
- The range of cushion thicknesses to be tested is very large, implying a large uncertainty in behaviour. An initial ranging shot to reduce this uncertainty and better define the required scan would be a better way forward.
- What modes or size of features can be resolved by the radiography configuration? Will any matrix imprint be diagnosable?
- The Omega FZP images show considerable moderate frequency modes. Whilst I appreciate this may not be representative of full scale NIF experiments, is there a mode spectrum requirement for the full NIF design?
- The conclusion that FY19 shots may identify an error in Be conductivity raises a lot of questions: What flux limiter is used? Is WDM conductivity relevant? If so Lee More is known to be poor in this regime due to exclusion of electron-electron scattering. Is laser absorption really ~100%?
- **Multi-Shell Direct-Drive Ablator Energetics**
- Double-shell implosions are a possible route to ignition and so the goals of this campaign are supported. The main issues are target fabrication and diagnosis. The 3D-printed foam lattice will have a large cell size, which will imprint and degrade the implosion. This needs to be assessed and other foam options considered.
- It is unclear why 50, 100 and 200um of CH cushion thickness are considered since it should be possible to down select to a narrower range with modelling.
- Radiographing the outside of the inner shell is possible, however, there is no obvious route to diagnosing the inside given the opaqueness of Cr.
- The implosion quality looks poor in the presented Hydra modelling, the laser absorption very high and the simulated trajectory does not match the NIF data. These differences need to be resolved and 3-D modelling applied. Consider changing the electron conduction flux limiter as an alternative to thermal conductivity scaling.

